Short paper:

Cross Training Policy for Field Technicians of a Servitized Company

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1. Problem Description

Original equipment manufacturers (OEMs) such as GE, Rolls-Royce and Siemens have recognized the importance of after sales service [1]. These manufacturers pursue a product service strategy in which they actively promote services to enhance the value proposition of their product offering.

As OEMs take over more and more maintenance activities of their customers, the maintenance organizations are becoming larger, more professional and more complex. This complexity is caused by the diversity of the machine park (installed base) that OEMs have to maintain. Typically the installed base will be scattered around the globe, contain a wide range of different machines that are supported by different technologies such as combustion or electronic engines, oil free or oil injected rotors. All these different technologies require specialized skills.

In general, maintenance organizations have to deal with two types of tasks. On the one hand, they will need to fix machines that have failed (repairs or corrective maintenance). On the other hand, they will try to avoid failures by performing preventive maintenance. Contrary to preventive maintenance, repairs cannot be planned in advance and have to be dealt with in an "as soon as possible" manner. To highlight this difference we will indicate repairs with the term "emergencies" while preventive maintenance jobs are referred to as "non emergencies". In this research, the cross training policy under consideration is to decide on the optimal fraction of technicians to dedicate to non emergencies. Moreover, the professionalization of the aftermarket service industry has led to a surge in the use of multi-period service contracts. In some of these contracts service providers take full responsibility for the functioning of the equipment. They will perform both preventive and corrective maintenance in order to maintain the machine, sometimes they are even giving up-time guarantees (performance based contracting). With such contracts in place, demand for service can be influenced by the OEM by setting proper maintenance policies and corresponding capacity levels. By taking responsibility for the entire maintenance of the machine, the OEM will be able to perform more preventive maintenance which translates itself in less repairs. By doing so, the OEM can steer its service organization towards more planned and less emergency activities. Therefore, comprehensive contracts offer the possibility to lower the uncertainty in the service demand which creates opportunities to optimize the service operations [2].

Advanced service providers have to make decisions concerning their workforce and the service product mix. How many technicians of the different skill levels need to be hired/trained? Which service products to offer? These questions are related: by performing more preventive maintenance the amount of breakdowns will go down, allowing a reduction in the workforce that can handle repairs but increasing the need for technicians to perform preventive maintenance. To the best of our knowledge, we are the first to study the impact of selling comprehensive long term service contracts on the service performance and the capacity requirements in a field service system. We performed a simulation study to investigate the interdependency between the cross training decisions and the service product mix. More specifically, we investigate the impact of the maintenance policy, the workload (number of machines being maintained) and the machine reliability on the optimal cross training policy. Moreover, we evaluate the attractiveness of selling more comprehensive service contracts both in terms of capacity requirements as in terms of the service performance. In the following section we present the key characteristics of our simulation model. In section 3 we give a flavor of the results of this ongoing research. In the last section, we conclude.

2. Field Service Model

In this section we will present the simulation model that is constructed in order to evaluate the possibility to deploy technicians dedicated to preventive maintenance. We captured the essence of a field service organization with a discrete time simulation model created in ARENA 11.0. To safeguard the applicability of our results we used real-life data from an existing service region of an OEM in the compressed air and generator industry. In the following paragraphs the assumptions and performance measures of the model will be discussed.

2.1 General Assumptions

In the service region under consideration 10 technicians or field service engineers (FSE) work to serve an installed base of machines. A significant part of this installed base is covered by comprehensive service contracts in which the OEM is responsible for both emergency and non emergency service. Demand from machines covered by a contract (D_{sc}) is more predictable than the demand of machines without a contract (D_r**)**. Both D_{sc} and D_r can be a request for emergency or non emergency service. The key difference is that D_{sc} is influenced by the maintenance policy and the system state, while D_r is independent of the OEM's maintenance policy and the system state. Therefore, we let jobs of D_r arrive according to a Poisson process and once executed the jobs are discarded. Machines with a service contract are explicitly modeled as entities in a closed-loop queuing system comparable to the approach in Papadopoulos [3]. Non emergency jobs on a machine under contract arrive with a fixed time interval dependent on the contract terms and the yearly operating hours of the machine**.** On the contrary, emergency jobs on a machine under contract arrive based on a failure process (see further). Between the different types of jobs we use a non-preemptive allocation priority for emergency jobs.

There are two types of technicians, i.e. technicians dedicated to non emergency service (N FSE) and fully cross trained technicians (E FSE) that can handle both emergencies and non emergencies.

One key advantage of non emergency jobs is the leeway in timely execution of these jobs. Preventive maintenance jobs are accepted to be on time if they are executed during an interval of 10% around the optimal preventive maintenance timing. This flexibility in timing of execution allows for non emergency jobs to be executed when there is idle capacity or to be postponed when work is piling up. Based on this reasoning and in order to capture the advantages of performing more preventive maintenance we allow that non emergency jobs can be started as soon as 10% before the timing foreseen in the maintenance contract (o_j). However, when the job is postponed for longer than 10% of the maintenance interval the job is considered to have become an emergency. We assume that when a failure occurs during the 10% interval around o_j both the repair and the preventive maintenance are performed during the same intervention (opportunistic maintenance).

2.2 Reliability of Machines

To model the maintenance demand originating from machines covered by a service contract (D_{sc}), we use a competing risk framework [4]. In this framework a stochastic process representing failures and another representing preventive maintenance compete against each other to materialize.

In order to model the time until the next failure after maintenance job *j* (X_j), we have to quantify the impact of maintenance on the failure rate (λ). In the standard competing risk approach it is assumed that each maintenance is perfect, i.e. after receiving maintenance the machine is as good as new (AGAN). In reality this is not the case, therefore we assume that after emergency maintenance the failure rate of the machine is the same as just before the failure which is a more plausible assumption. For non emergency maintenance we keep the assumption of AGAN maintenance. As a consequence, the failure intensity is determined by the time that has passed since the last preventive maintenance job on the machine (t_{pm}). We assume that the failure intensity or hazard function can be modeled by the widely used Power Law Process [5]:

$$\lambda(t_{pm}) = \frac{\beta}{\alpha}\left(\frac{t_{pm}}{\alpha}\right)^{\beta-1} . \qquad (1)$$

with α = scale parameter
β = shape parameter

For a Power Law intensity function the time to failure after a maintenance intervention *j* (X_j) can be represented as a truncated Weibull distribution.

$$X_j \sim Weibull(x \mid x > t_{pm}) - t_{pm} \qquad (2)$$

The time to failure obtained in this way is in line with the Power Law process. We have linked the demand for service (emergency and non emergency) with the maintenance policy followed by the service provider. Moreover, the demand is dependent on the state of the service system. Indeed, when there is too much work to be done for the FSEs, preventive maintenance is stalled which will lead to more machines failures due to the increasing failure rate in function of t_{pm}.

3. Results

In this section we discuss the results of our simulations. We tested the attractiveness of deploying technicians dedicated to non emergency maintenance in a wide range of scenarios. The scenarios differ in terms of the maintenance policy (maintenance frequency), the total workload and the reliability of the machines. In total we use 16 different scenarios for which the optimal cross training policy is determined. By doing so, we obtain insights about the factors that impact the cross training decision and the attractiveness of increasing the fraction of the installed base covered by a service contract.

3.1 Direct and Indirect Impact of PM Dedicated Technicians

To evaluate the service performance we use the average machine availability which can be derived from the simulation results. To test the performance of the different cross training possibilities we take the following approach: for each scenario we will start with 10 E FSEs and gradually replace them with N FSEs. This evolution in the workforce mix can be captured by the ratio

$$R_n = \frac{S_n}{S_e + s_n}$$

with s_n the number of N FSE
s_e the number of E FSE .

When the number of technicians dedicated to non emergencies (S_n) increases the ratio goes up. We opted to maximize the service performance while keeping the budget for FSE constant. As a consequence, we start with a situation of 10 fully cross trained technicians (budget fully used) and progressively switch fully cross trained technicians for dedicated ones. Thanks to the fact that the cost of a N FSE amount only to 2/3 of the cost of an E FSE, two E FSEs can be replaced by three N FSE without exceeding the budget. So after switching one E FSE for one N FSE $(R_n = 0{,}1)$, we can replace two E FSE by three N FSE $(R_n = 0{,}27)$, ... Among these workforce configurations we then select the one which achieves the highest average availability for the machines under contract.

Having more N FSEs on the payroll can improve the timely execution of preventive maintenance jobs. This is a consequence of the fact that E FSEs give priority to emergencies before non emergencies. Therefore, if there is a capacity shortage preventive maintenance jobs are the first to be postponed. This however endangers the timely execution of preventive maintenance. Without timely execution of preventive maintenance, the total number of emergencies rises due to machine breakdowns. This will in turn increase the need to postpone some jobs, once again endangering timely preventive maintenance and further increasing the number of emergencies ... The use of N FSEs can avoid this "emergency trap" of an escalating number of emergencies due to postponement of preventive maintenance. Replacing E FSEs by N FSEs has a direct and an indirect effect. Obviously, the lower number of technicians to handle emergencies will increase the response time for these emergencies while lowering the response time for non emergencies (direct effect). On the other hand, the improvement in timely preventive maintenance will reduce the total number of emergencies which will reduce the response time for the remaining emergencies. This indirect effect of timely preventive maintenance on the number of emergencies may tip the balance in favor of employing more dedicated technicians.

Figure 1 shows the average availability for the scenario with preventive maintenance after each 3000 operating hours, a hazard function of PL(3175,5) and a high workload. The first FSEs which are reserved to perform only preventive maintenance strongly reduce the response time of both non emergencies and emergencies. As these FSEs will focus on non emergency service a lot of emergencies will be avoided (indirect effect), offsetting the increase in emergency response time due to the reduction of E FSEs (direct effect). So the introduction of the first N FSE increases the availability. But as the proportion of N FSE increases the positive effect on the number of emergencies decreases. The response time of non emergencies continues to decrease but this positive effect is canceled out by the increase in emergency response time. The increasing response time for emergencies deteriorates the availability of the machines. From figure 1 it is clear that a FSE configuration with a R_n of 0,27 is optimal with respect to the machine availability.

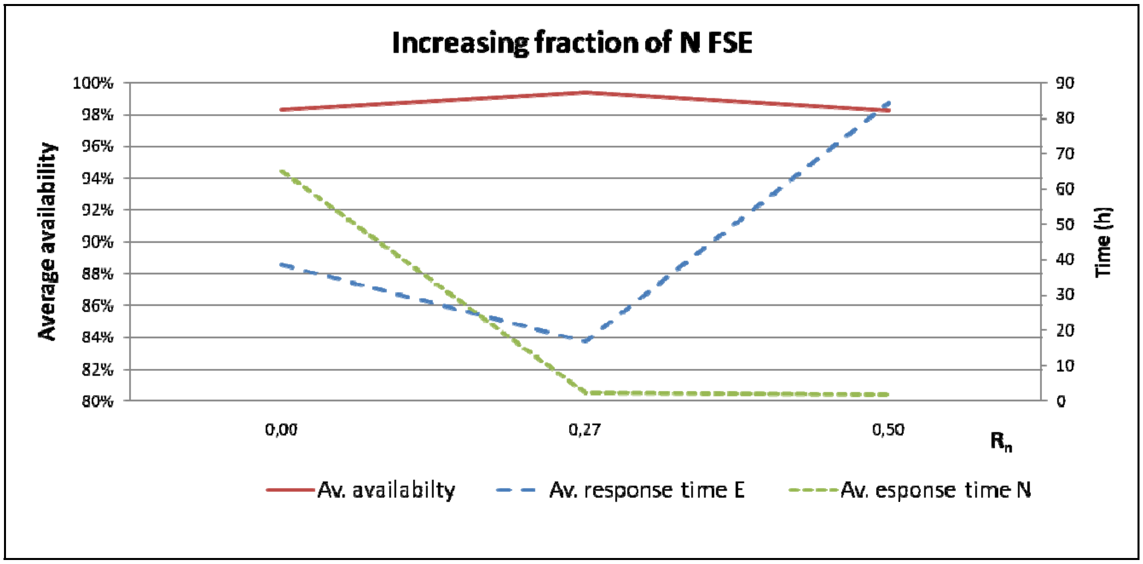

Fig. 1. Service performance with increasing specialization with high workload

3.2 Factors Influencing the Cross Training Policy

It became clear from our simulation results that the evolution as shown in figure 1 strongly depends on the workload, i.e. if a high number of machines needs to be maintained deploying N FSE becomes more attractive. This observation can be explained by the fact that when the workload is not high, the E FSEs will have plenty of time to perform the non emergency services in a timely matter. It is only when E FSEs are overwhelmed by work that they will be pre-occupied by emergencies and neglect preventive maintenance. With the spotlight on emergencies, preventive maintenance will be postponed, further increasing the workload as more and more machines fail. The fact that the workload plays a leading role in determining the cross training policy collides with the conclusion of Chakravarthy and Agnihothri [6] who found that the utilization rate of the technicians is a crucial parameter for the optimal cross training policy.

Although a high workload can justify the deployment of N FSE, N FSE can be attractive even with a standard workload but only if the machines are highly reliable, i.e. there are very few emergencies. Furthermore, also the machine failure characteristics around the time of preventive maintenance play a role. Once the timely execution of preventive maintenance is jeopardized, the optimal amount of N FSE to deploy increases, if the reliability degrades faster around the time of preventive maintenance.

3.3 Impact of Increased Contract Coverage

Following their desire to increase the service business, servitizing companies will actively promote the use of service contracts. But how to assess the attractiveness of such a strategy and what are the implications for the cross training policy?

By adapting the demand in our simulation model by decreasing the demand of service outside a service contract (D_r) and putting more machines under a contract (D_{sc}), we can evaluate the impact of an increased level of servitization (more contract selling). Increasing the contract coverage (in most cases) leads to an increase of the fraction of non emergency interventions compared to emergencies. This creates the possibility to optimize the service operations (capacity) and deliver better service performance to customers. Once again, the combination of the maintenance policy and the reliability of the machines will determine the size of both the direct and indirect effect of adding N FSE. By using the failure function and the failure counting processes, we are able to mathematically derive estimations of these effects and accordingly the impact of increasing the contract coverage on the service performance.

4. Conclusion

In this paper we reported on the main results of a simulation study in which we modeled the field service operations of an OEM in the compressed air and generator industry. The simulation model takes into account some of the key characteristics of field service systems such as traveling, job allocation in discrete time and the use of long term service contracts that combine preventive and corrective maintenance. As maintenance providers feel the pressure to deliver excellent service while containing costs, determining the optimal cross training policy becomes vital.

We evaluated the impact of the workload, the machine reliability, and the maintenance policy on the cross training policy based on the service performance using realistic data values. The deployment of technicians dedicated to preventive maintenance (non emergencies) avoids that preventive maintenance is postponed too long due to more urgent machine failures. The timely execution of preventive maintenance on his turn will lower the total amount of machine failures possibly offsetting the negative effect of having less fully skilled technicians. Employing technicians dedicated to preventive maintenance turns out to be optimal if the workload is high or when the machines are highly reliable up to the time of preventive maintenance. Increasing the contract coverage of the installed base can be a worthwhile strategy if the maintenance policy is well suited for the reliability characteristics of the machines.

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